IMPACT CHEMISTRY OF SERPENTINE-IRON PLANETESIMALS

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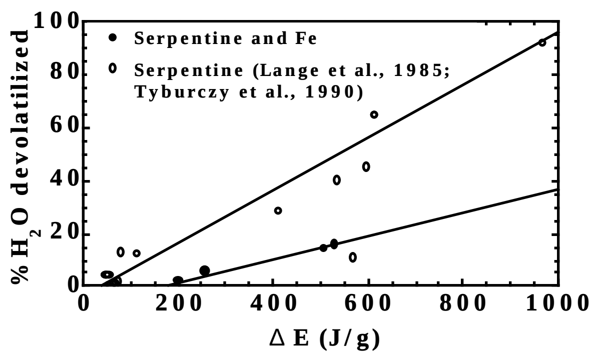
ABSTRACT. The amount of water devolatilizing in porous silicate-metal mixtures on impact is less than that of both porous and non-porous serpentine at similar internal energies [2,3].

INTRODUCTION. Devolatilization and chemical reactions between volatiles and iron contained in the accreting planetesimals will modulate the formation of the planet's initial atmosphere, affect its mantle and core chemistry [1]. Previous work on impact-induced devolatilization in serpentine, Murchison meteorite, serpentine-iron, and serpentine-pyrrhotite mixtures [2,3,4,5] studied the range of pressures over which dehydration occured, and applied these results to models of impact-induced dehydration during planetary accretion. . In this study, we present new data on devolatilization for serpentine-iron mixtures, examine differences in devolatilization with shock pressure between the mixtures and serpentine alone [3], and compare our experimental data with previous Earth accretion models [e.g. 1,6].

EXPERIMENTAL. We performed additional solid-recovery impact experiments on mixtures of serpentine and iron powders (50:50 by mass) using the 20 mm solid propellant gun at Caltech. The mixed powder was pressed into a stainless steel recovery assembly, with initial densities 87 to 100% (± 7%) of the theoretical density. The samples were impacted at velocities from 1.46 to 1.88 km/s using a stainless steel flyer plate held in a Lexan projectile. To calculate the initial shock pressures in the samples, we constructed mixed phase equations of state for the fully dense material, from endmember equations of state [7,8], and then obtained the Hugoniot pressure for the porous material [3,8]. Samples were recovered from the assembly after each experiment, and analyzed for H_2O content using the methods described in [5].

RESULTS AND DISCUSSION. Impact induced dehydration of serpentine and iron mixtures as a function of internal energy along the Hugoniot is shown in Figure 1. Our main result is given above.

Fig. 1

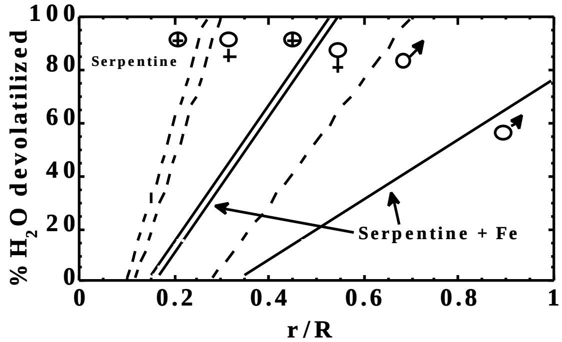


This demonstrates that the addition of iron, with its higher bulk modulus than serpentine, leads to a lower internal energy (less volume compression and shock heating) in the mixture. Therefore, dehydration in serpentine-metal mixtures is expected to persist to higher shock pressures than in serpentine alone.

Models based upon our serpentine-iron data (Fig. 2) predict that dehydration of infalling Fe-rich planetesimals would begin at 14, 16, and 35 % of the present day radius for Earth, Venus, and Mars and 100% devolatilization would occur at 54 and 56% of the present day radii of the Earth and Venus respectively. Mars is expected to have reached its present day radius before the parent material reached 100% devolatilization on impact.

This is quite different than the degree of dehydration as a function of planetary radius predicted based upon serpentine data in the absence of iron [3] and that predicted based upon shock data for Murchison meteorite [4]. These models indicated an earlier onset of dehydration, and smaller planetary radius upon which the accreting material completely devolatilizes on impact (Fig. 2). Therefore, the presence of metallic phases in accreting planetesimals have a significant effect on their impact induced dehydration during accretion.

Fig. 2

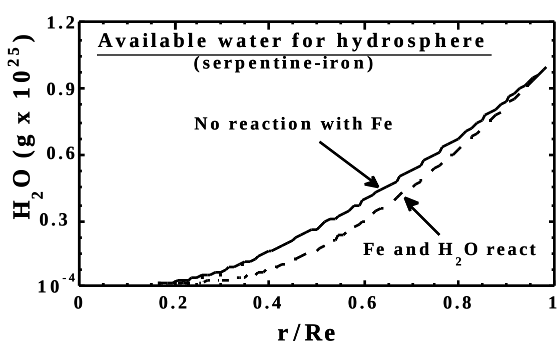


Isotopic data for shocked serpentine-iron samples indicates that H partitions more strongly into the evolved gas [5]. The associated gas-solid fractionation factors (α from D/H ratios) preliminarily indicate a change from that expected from serpentine and Murchison data [9]. This indicates a reaction between iron and devolatilized water from the serpentine may occur under shock loading of the mixture. Iron may react with the enstatite and water fraction of the dehydration products of serpentine balanced according to [1]:

(1) $Mg_3Si_2O_5(OH)_4 + Fe \rightarrow 3/2Mg_2SiO_4$ (Fo) $+ 1/2Fe_2SiO_4$ (Fa) $+ H_2O + H_2$

The effect of this reaction on the amount of water available to form the Earth's hydrosphere is shown in Figure 3, assuming a present day terrestrial water content of ~10^{25} grams [e.g. 1,6].

Fig. 3



This preliminary model illustrates that given an impact induced devolatilization curve for Fe-bearing planetesimals, and assuming reaction 1 occurs, accumulation of the present terrestrial water budget may be explained without requiring mechanisms for loss of accreted water. We expect to constrain the dehydration history of the terrestrial planets during accretion, as well as the resulting Fe chemistry (metallic vs oxidized) of planetary mantles.

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